Why is Space Flight So Difficult ?

A Look at Kinetic Energy Requirements for Orbital Flight

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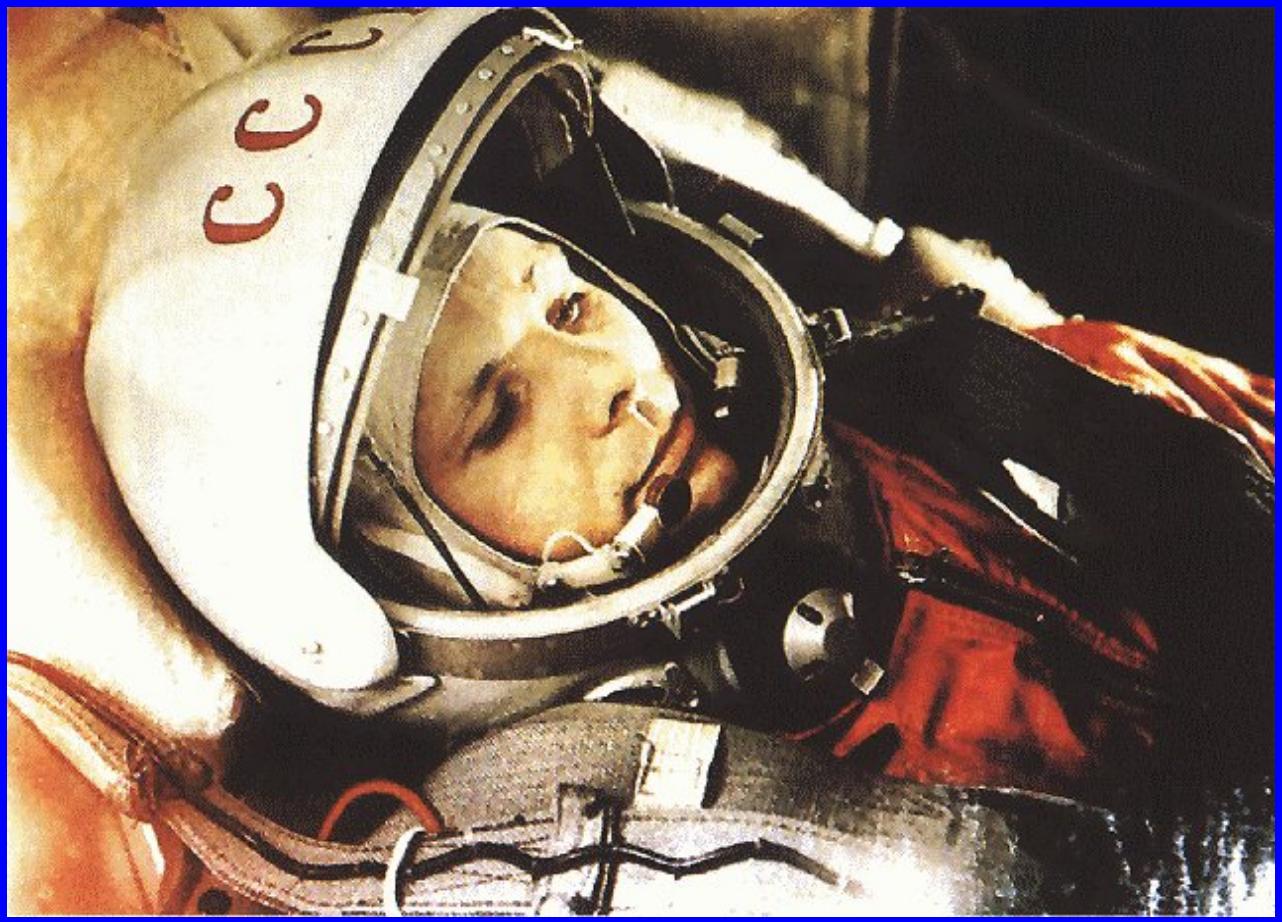
22nd AMSAT Annual Meeting and Space Symposium

Arlington, Virginia

30 years after the Wright Brothers made their first airplane flight, reasonably well-off people could buy a ticket for commercial airplane travel.



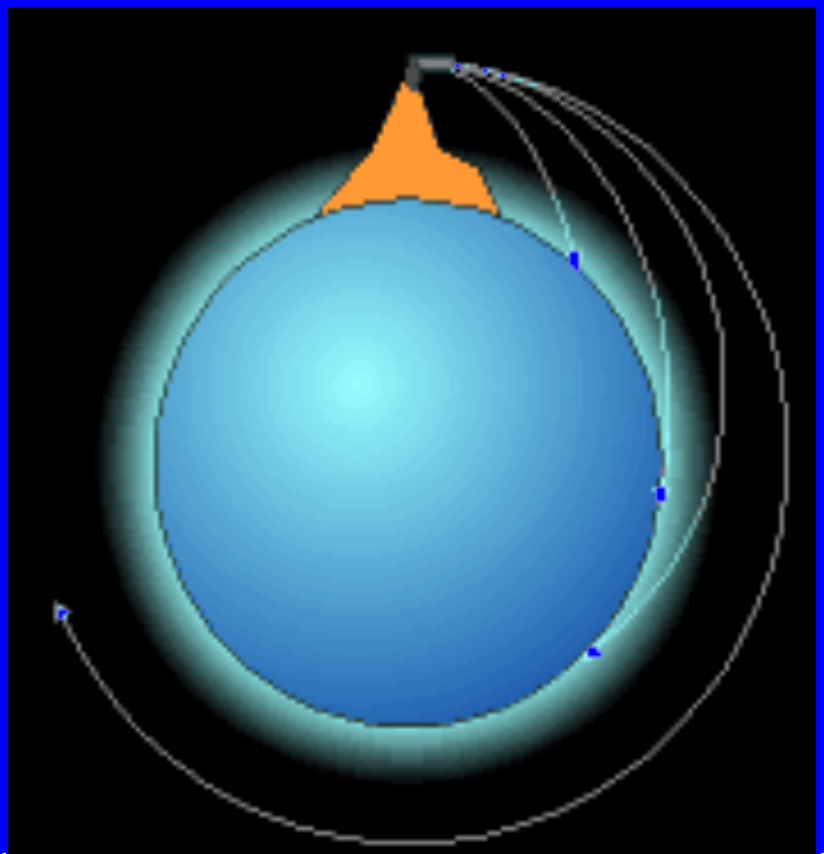
It is now 43 years after Yuri Gagarin made the first manned space flight, so why don't we have commercial space flight available to the public?

The X Prize - SpaceShipOne, October 4, 2004

$10 million prize for privately funded suborbital flight to 100 kilometers altitude with three people (or equivalent weight), repeated again in less than two weeks with the same vehicle.

There is much confusion about what is meant by “Space Flight”. The news media often reports that the $20 million SpaceShipOne is a replacement for the NASA Space Shuttle. The Washington Post wrongly reported it as an ORBITAL flight!!! Suborbital flight is a long way from orbital flight. Mike Melvill’s name may go down in history with Alan Shepard, but not with Yuri Gagarin.

Isaac Newton explained how to place things in orbit in "Principia Mathematica", published in 1687:



He recommended finding a very high mountain and using a very powerful cannon. As you fire the cannon with more gunpowder, the projectile achieves higher velocity and greater range. Eventually the range exceeds the curvature of the Earth and the projectile never hits the ground.

Astronauts are weightless because they are falling objects. You can be weightless for a few seconds if you jump off the top of this building. The only difference is that astronauts never hit the ground.

Achieving high altitude DOES NOT, by itself, put you in orbit.

Schultz's Laws of Space Flight:

1. <u>Get above the atmosphere as quickly as possible.</u>

Since there are no mountains tall enough to reach above the atmosphere, you need some sort of vehicle to climb to this altitude. Climbing slowly with a rocket wastes energy.

2. <u>Make a 90 degree turn and start hauling the mail until you acquire the magic velocity.</u>

$F = G M m / r^2 = m v^2 / r$

$V = \text{sqr}(G M / r)$

$V = 7800$ meters/second

(at 300 km altitude)

17,500 miles per hour

Any less than that and your satellite falls back to Earth!

Aerodynamic drag is the product of air density times velocity squared.

$$\text{Drag} = Cp * \text{air density} * \text{Velocity}^2$$

During rocket ascent, velocity increases as air density decreases. At liftoff the velocity is low and air density is high, in orbit the velocity is high but air density is extremely low. At some point during the climb to orbit, the product of velocity times air density reaches a maximum value.

“MAX-Q” is the rocket man’s term for the point of maximum aerodynamic pressure on the launch vehicle.

The Space Shuttle is designed to throttle down its engines to 65% thrust for passage through MAX-Q.

The “GO AT THROTTLE UP” call signals that MAX-Q has been passed and engines can resume full thrust for maximum acceleration.

Kinetic Energy = $^1/_2$ M V^2

For a 200 pound man:

1. Riding in a car - 60 miles per hour

Kinetic Energy = 32,600 Joules

2. Flying on Commercial Jet Airplane - 600 miles per hour

Kinetic Energy = 3,260,000 Joules (factor of 100 increase over car)

3. Suborbital X-prize entry SpaceShipOne - 2150 miles per hour

Kinetic Energy = 41,900,000 Joules (12 times passenger jet)

4. Flying in low Earth Orbit - 17,500 miles per hour

Kinetic Energy = 2,776,000,000 Joules

(factor of 850 increase over passenger jet)

(factor of 66 increase over SpaceShipOne)

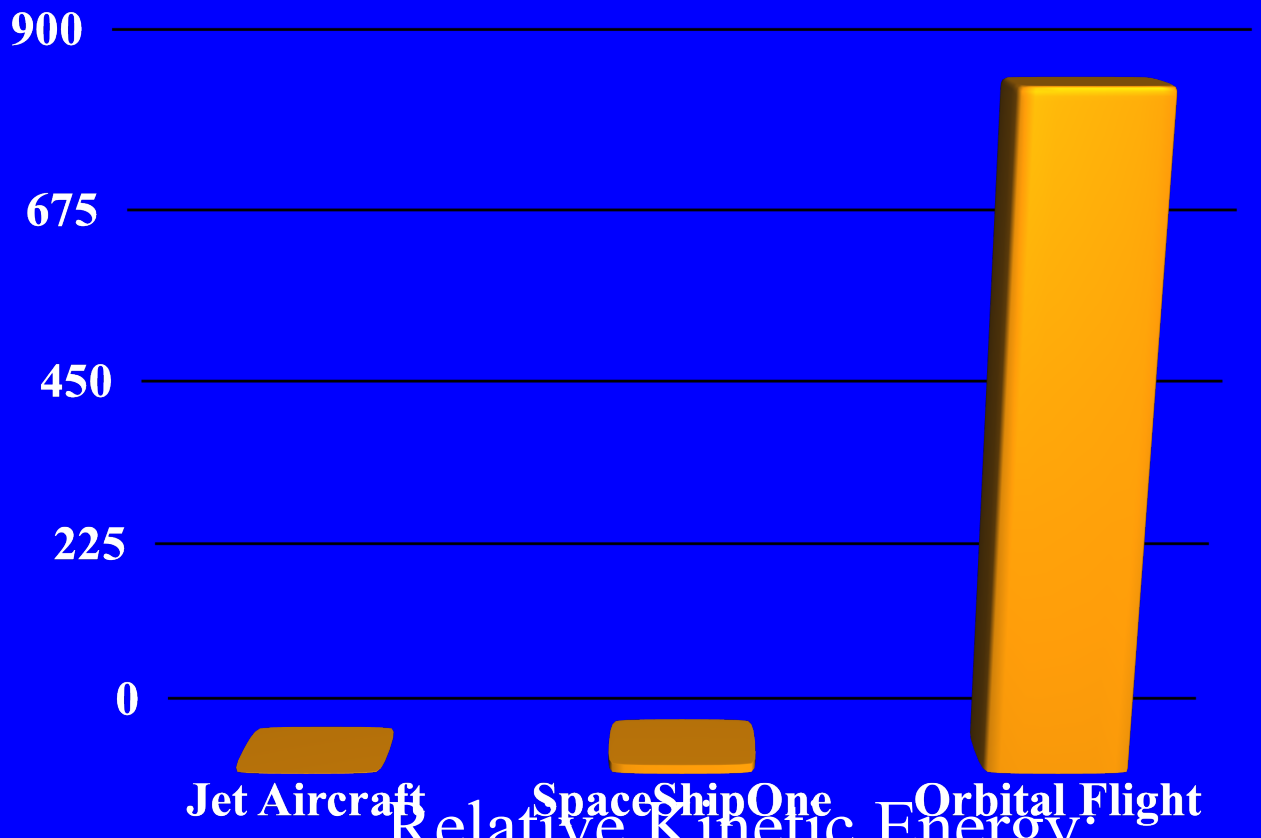
This energy must be obtained by burning a large amount of chemical propellant at the start of the mission. Any vehicle capable of propelling itself into orbit is inherently dangerous no matter how well it is designed.

Most of the velocity comes in the final minutes of the ascent to orbit. As fuel is burned off the vehicle mass is lightened and acceleration increases. The Space Shuttle's mass at Main Engine Cut Off (MECO) is 8.5 % of its initial mass at liftoff ten minutes earlier.

The orbital kinetic energy must be dissipated by atmospheric friction at the end of the mission. As we were reminded on February 1, 2003, coming back from orbit is dangerous also.

The kinetic energy of the Space Shuttle orbiter at the start of atmospheric entry is $4.2 * 10^{12}$ joules, equal to the electrical energy output of a large nuclear power plant for one hour.

During the 15 minutes of reentry heating, the heat dissipation on the orbiter is equal to the output of 4 large nuclear power plants.



Relative Kinetic Energy:

Jet Aircraft	1
SpaceShipOne	12
Orbital Spacecraft	850

SpaceShipOne is much closer to a passenger jet than it is to an orbital spacecraft when you consider the Kinetic Energy!

SpaceShipOne's goal is to offer tourist rides for $40,000 per seat, about $200 per pound, to accelerate a person to 2150 miles per hour.

17,500 miles per hour would be 8.1 times faster or 66 times more kinetic energy. $200 x 66 would be $13,200 per pound accelerated to orbital velocity with the same technology, if cost scales linearly with kinetic energy.

At that price, a 40,000 pound Space Shuttle payload would cost $528 million, not too different from the current NASA cost to launch the Space Shuttle…

But cost DOES NOT scale with kinetic energy, it's EVEN WORSE than that...

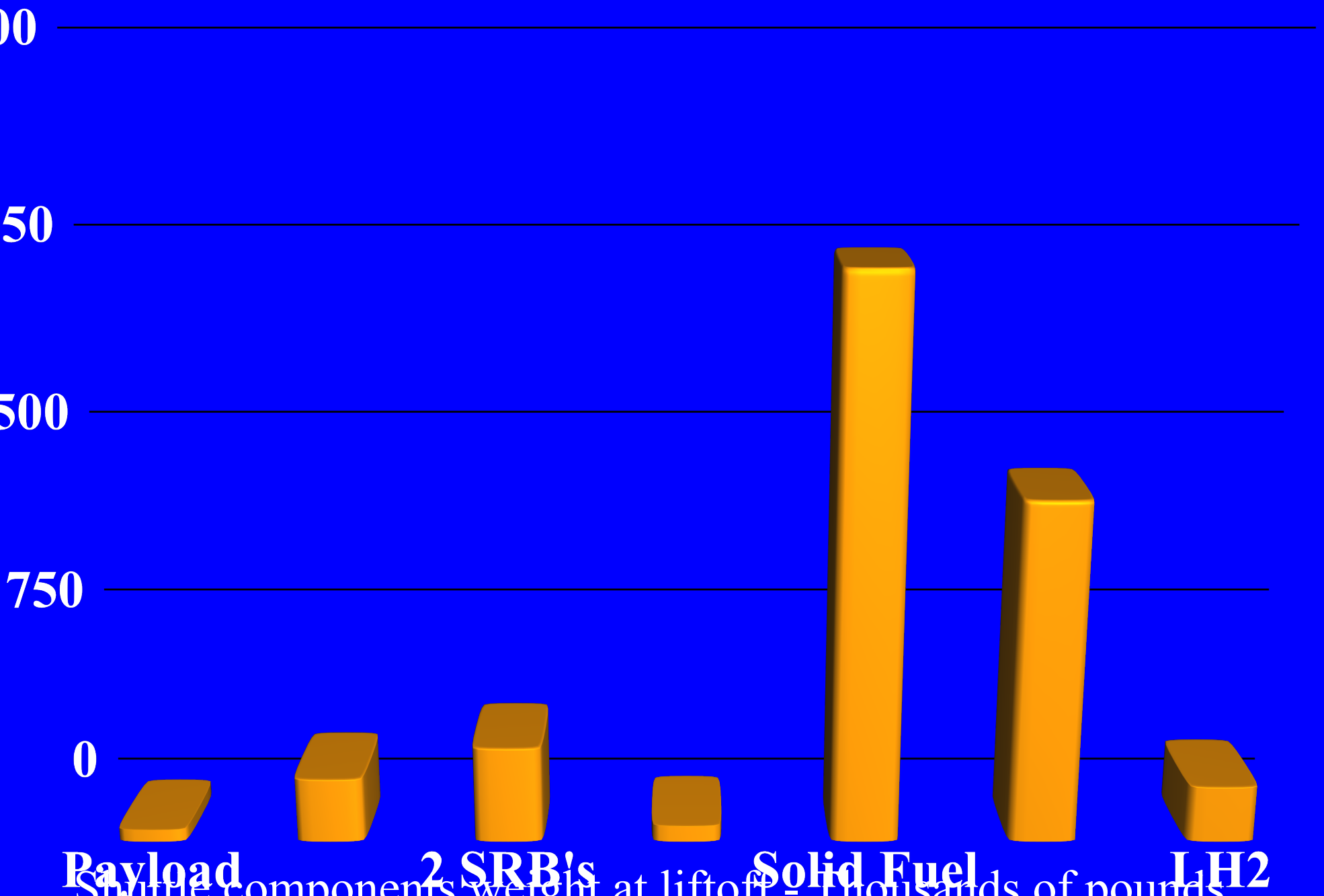
If we want to place SpaceShipOne into orbit, we need to burn 66 times as much fuel to get the required kinetic energy. In order to carry that fuel with us, we need 66 times larger fuel tanks, but then the spaceship mass is increased because of the larger tanks, so we need EVEN MORE fuel and still BIGGER TANKS, and so on!

Konstantin Tsiolkovsky's Rocket Equation:

$$V_{final} = V_{exhaust} * Log_n (Mass_{initial} / Mass_{final}) + V_{initial}$$

The mass ratio ($Mass_{initial} / Mass_{final}$) defines the final velocity and determines the amount of fuel required to achieve a desired velocity. For a given exhaust velocity, the delta V performance is determined by the amount of mass expelled from the vehicle. This determines that the Space Shuttle must expel 91.5 % of its initial mass in order to reach orbital velocity.

Recall from high school chemistry that an oxygen atom weighs 16 times as much as a hydrogen atom, so the oxygen supply for the rocket is in an 8:1 weight ratio to the hydrogen (for H_2O exhaust). Most rockets actually operate a little bit fuel rich, the Space Shuttle uses a 6:1 oxygen to hydrogen weight ratio. (Excess unburned hydrogen in the exhaust plume increases exhaust velocity because of its lower molecular weight).



Shuttle components weight at liftoff – Thousands of pounds

Total liftoff weight 4,400,000 lbs, (91.5 % is fuel)

Weight at MECO 373,000 lbs. (8.5 % of liftoff weight)

The Liquid Oxygen in the Shuttle's External Tank weighs twice as much as all of the flight hardware! (Orbiter, payload, empty External Tank, and empty Solid Rocket casings)

The Solid Rocket Boosters are there just to lift the oxygen off the ground!

Can we get into space without carrying the oxygen with us?

The Aerospace Plane:

Pro:

Sucks its oxygen from the Earth's atmosphere like an airplane, no need to carry it in a tank or lift it off the ground.

Con:

Violates our First Law: Attempts to achieve high velocity while still in the atmosphere. Atmospheric drag removes energy at the same time that its engines are trying to add energy. (Most space plane designs use a small rocket for the final push to orbit.)

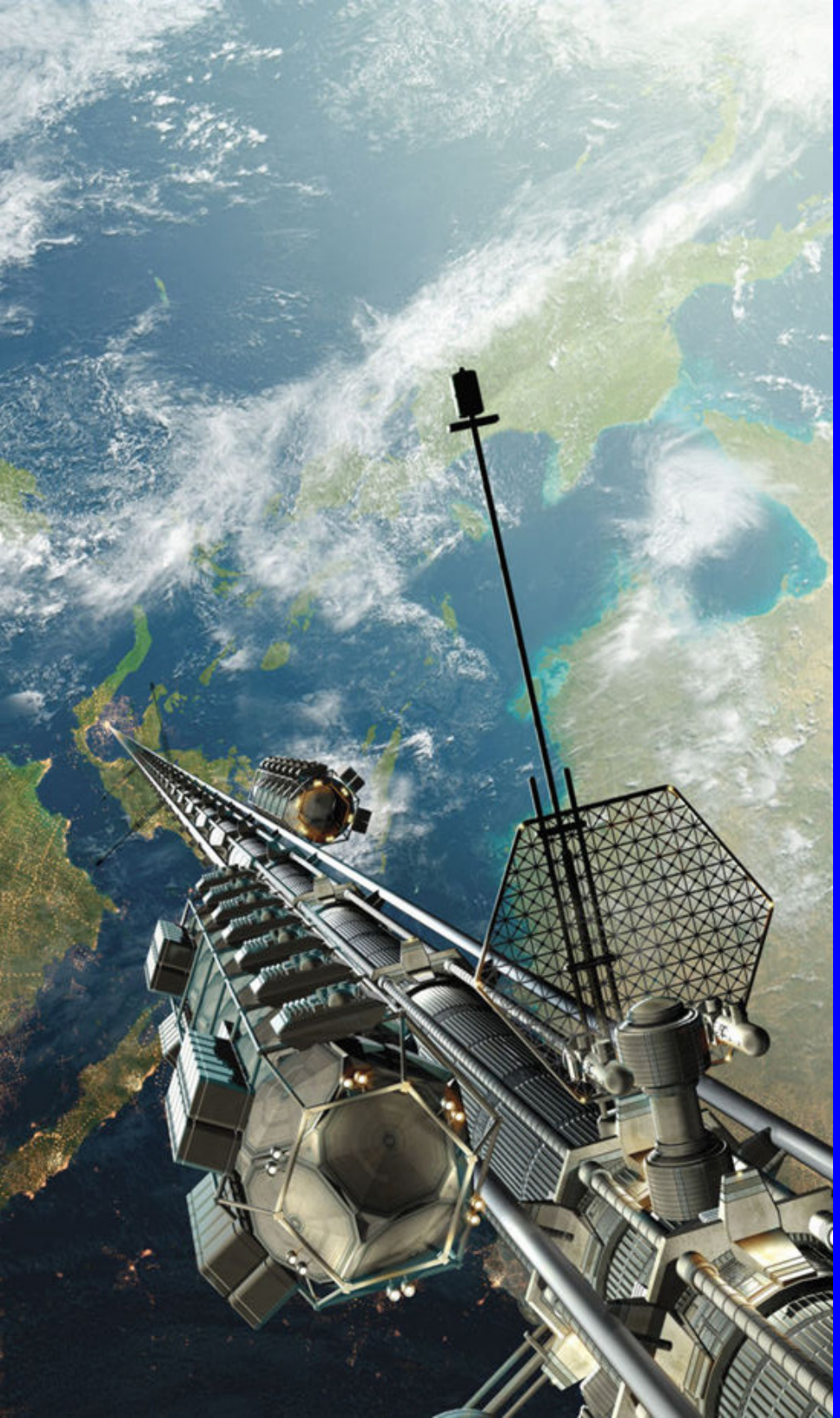
Space Plane technology is highly classified due to military applications. (There could be work going on that we don't know about.)

A commercial jet is already above most of the atmosphere.

Orbital Sciences' Pegasus Rocket takes advantage of this.

Lifting a fully loaded Shuttle on a jet airliner is a different matter though.

(The Shuttle is not carrying any fuel when it rides on the back of the NASA 747.)



The Space Elevator:

Konstantin Tsiolkovsky (1857-1935)

Featured in “The Fountains of Paradise” by Arthur C. Clarke

A simple concept: Start with a satellite in geosynchronous orbit, drop a cable down to Earth’s equator and another cable farther out to keep the center of gravity in GEO orbit. Attach an elevator car to the cable and push the “up” button. When you reach the 12 millionth floor, step off the elevator and you are in geosynchronous orbit!

Simple rocket transfers can take you to other orbits as needed.

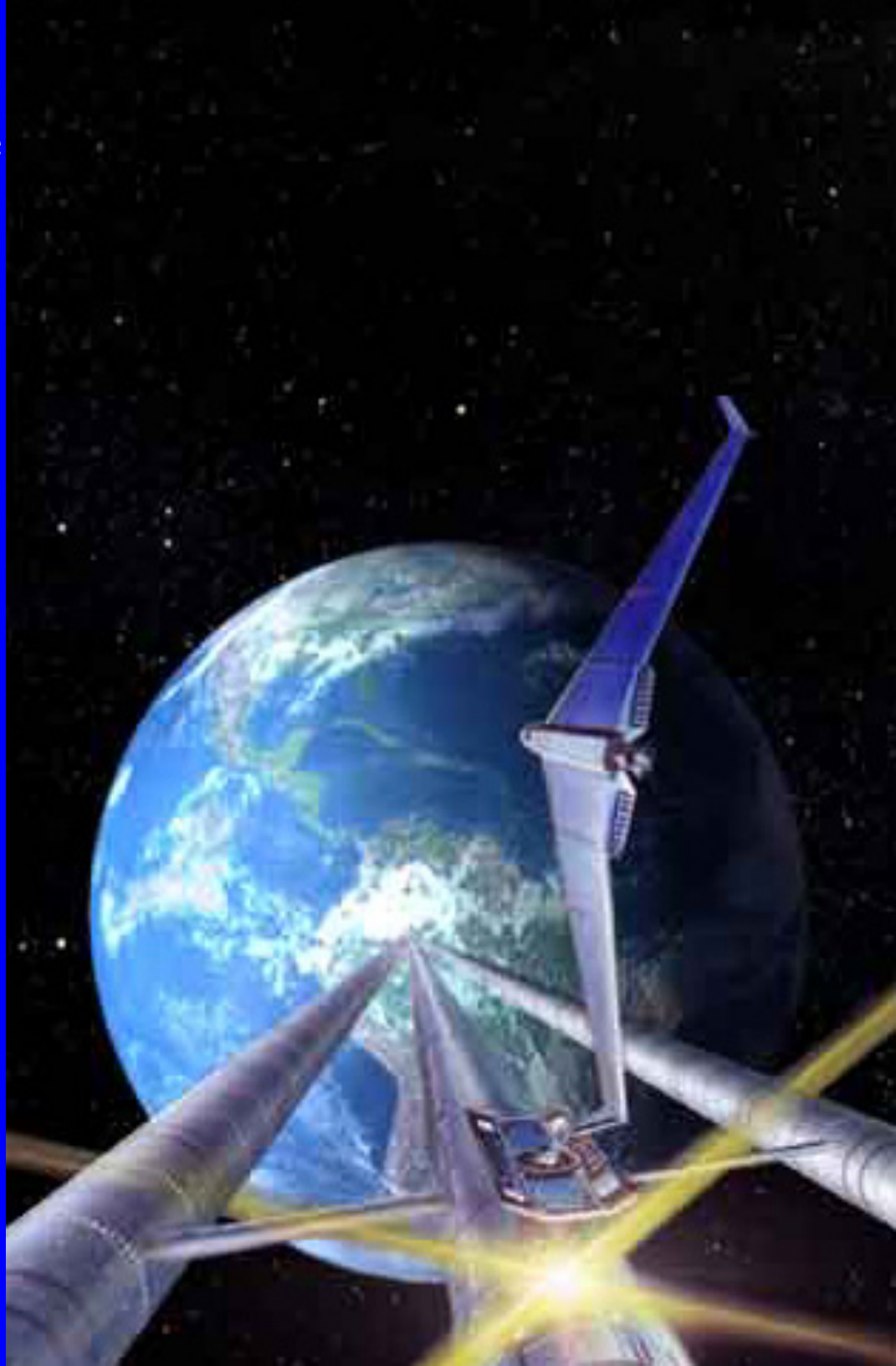
Painting by Chris Wren, Mondolithic Studios

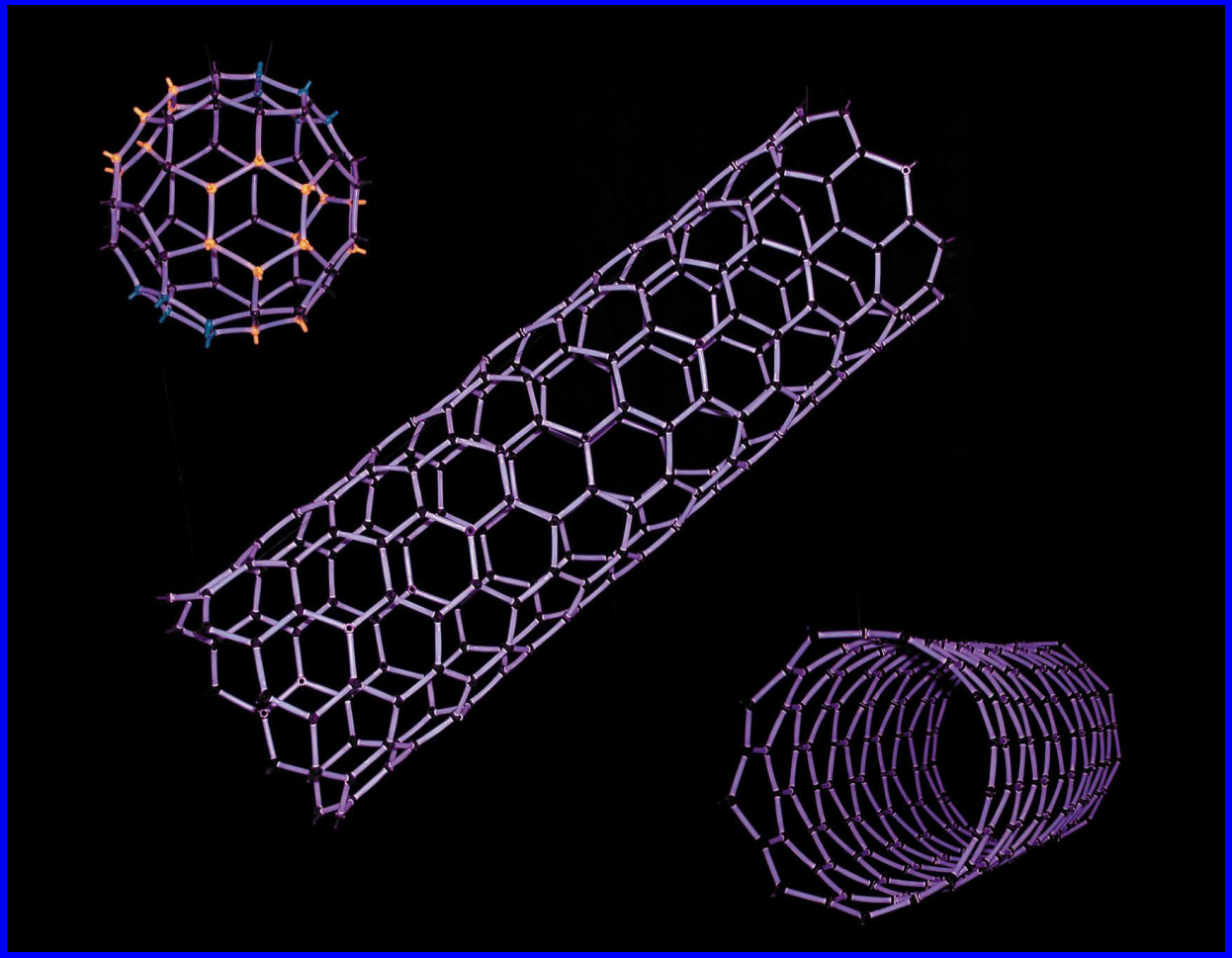
There is no need to carry tons of explosive rocket fuel with you. The only incremental cost would be a few dollars per pound for the electricity to run the elevator car.

A Space Elevator would open a highway between Earth's surface and Geosynchronous orbit.

It would change Earth's economy in ways we cannot imagine today.

Painting by Don Dixon, cosmographica.com





The main problem - no known material exists that can support its own weight for 23,000 miles of cable - Until recently:

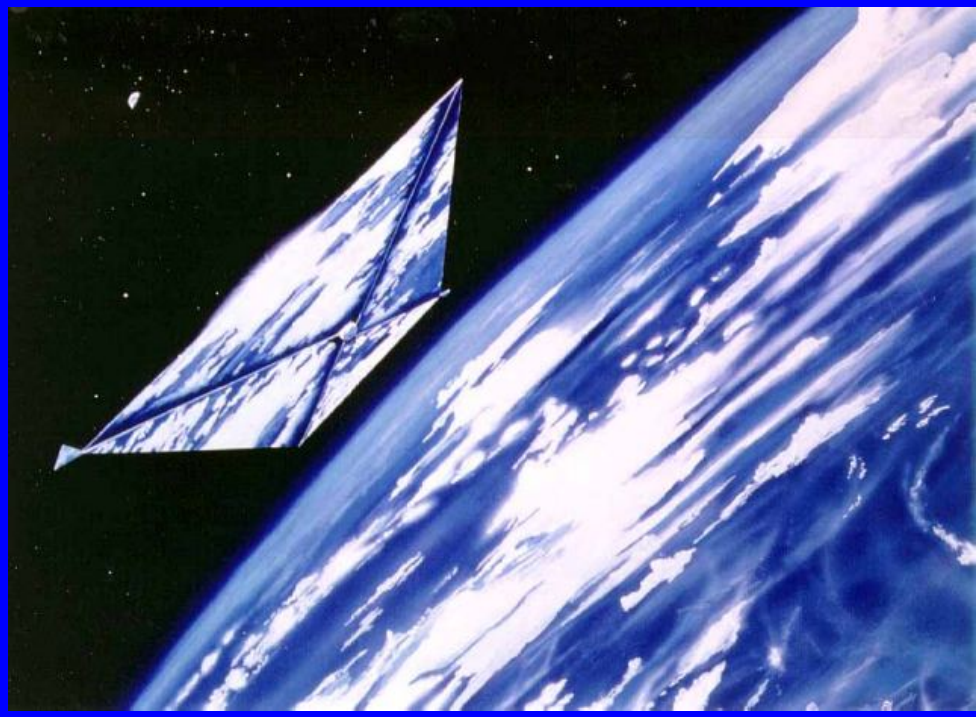
Carbon Nanotubes (a variation of Buckyballs) have the necessary tensile strength, but today they are a laboratory curiosity. Can we scale them up to industrial production levels, so that they are no longer Unobtanium?

“Will be built about 50 years after they stop laughing”- Arthur C. Clarke

"Once you get to Earth orbit, you're halfway to anywhere in the solar system." -- Robert Heinlein

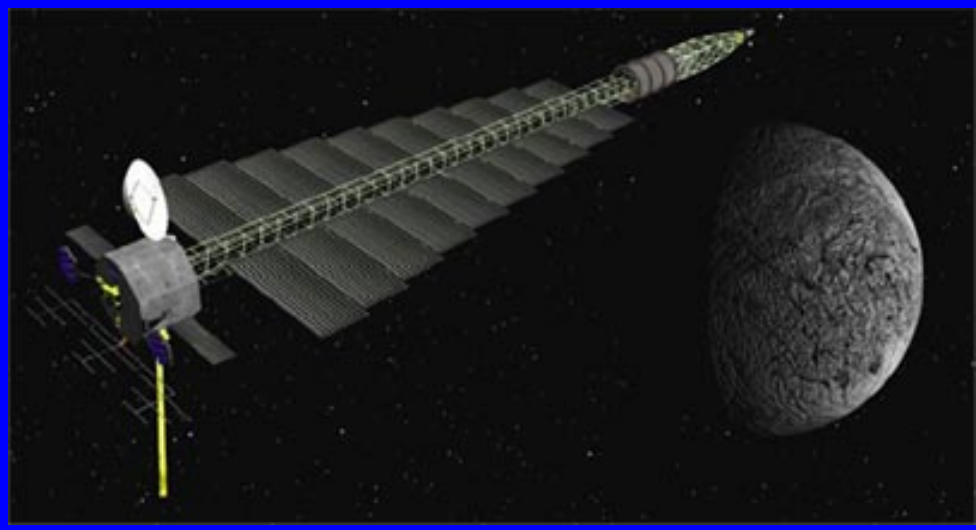
Once you are free of Earth's atmosphere the rules change dramatically:

Low Thrust Propulsion is possible:



Solar Sails use the momentum of sunlight to achieve high velocity over time. With a little patience you can build up a huge velocity.

Electric Propulsion, solar or nuclear power source: Project Prometheus, Jupiter Icy Moons Orbiter



There are smaller electric propulsion systems that could be useful for AMSAT missions.

Lunar resources -

The excitement about finding water at the lunar poles is that water could provide a source of hydrogen and oxygen for refueling space vehicles, with no need to lift those fuels from Earth.

If we can't get water on the moon, there is still oxygen in the moon rocks which we could obtain at some expense of energy, and bring only the hydrogen up from Earth at 1/8 of the weight.

Since there is no atmosphere on the moon, our first rule of space flight does not apply. You are free to accelerate to orbital velocity even at the lunar surface. An electromagnetic rail gun could sling buckets of lunar soil or processed rocket fuel out into space at very low cost.

Hubble Update

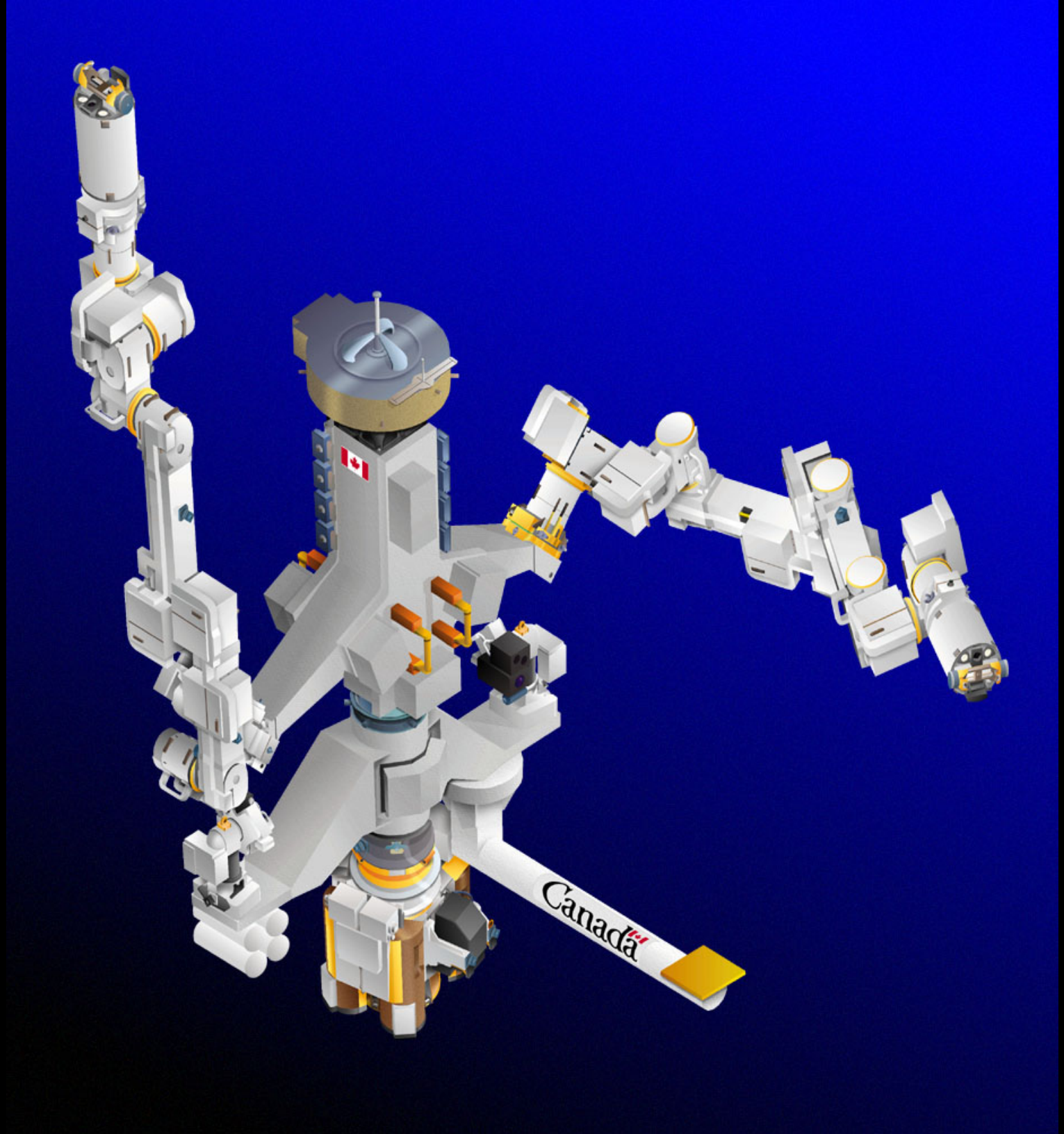
January 16: NASA Administrator Sean O'Keefe declares that Service Mission 4 (which would have been the 5th service mission) will not be flown because of Shuttle safety concerns.

January 29: Senator Mikulski and other members of Congress request independent review of this decision.

July 13: National Academy of Sciences releases interim report, recommends that NASA "take no action that would preclude a Space Shuttle servicing mission to HST."

September 22: Senate Appropriations Sub Committee on Space approves an emergency appropriations bill for NASA covering Hubble Robotic service mission.

October 1: NASA issues sole-source Request for Proposal to MD Robotics of Canada for "Special Purpose Dexterous Manipulator" device.


Canada

Columbia Accident Investigation Board recommends recertifying the Space Shuttle by 2010 if it is to keep flying after that date.

That would be almost as expensive as building a new shuttle from scratch, so NASA's plan is thus to retire the shuttle in 2010.

They figure 5 flights per year, with 25 flights needed to finish the ISS. Therefore no room in the schedule for a Hubble mission.

Astronauts are willing to fly the mission, many signed a petition that they be allowed to do so. One big issue is the extensive training required to conduct on-orbit repairs to the shuttle, which would be in addition to the extensive training required for a Hubble service mission.